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Lesson 10: Representing, Naming, and Evaluating Functions

Student Outcomes

* Students understand that a function from one set (called the domain) to another set (called the range) assigns each element of the domain to exactly one element of the range and understand that if *f* is a function and *x* is an element of its domain, then *f(x)* denotes the output of *f* corresponding to the input *x*.
* Students use function notation, evaluate functions for inputs in their domains, and interpret statements that use function notation in terms of a context.

Lesson Notes

This lesson is a continuation of the work from Lesson 9. In this lesson, we develop the idea of using a formula to define a function (e.g., the function , where ) and lead students to fully understand why we can use the equal sign (=) in this way to define a function. The lesson also includes exercises that build fluency with evaluating functions, identifying the domain and the range based on the definition of an algebraic function, and interpreting functions in context. The definitions and FAQs for teachers below will be important to today’s lesson. We start with a definition of polynomial function:

**POLYNOMIAL FUNCTION.** Given a polynomial expression in one variable, a *polynomial function* is a function such that for each real number in the domain, is the value found by substituting the number into all instances of the variable symbol in the polynomial expression and evaluating.

It can be shown that if a function is a nonzero polynomial function, then there is some non-negative integer and collection of real numbers with such that the function satisfies the equation,

for every real number in the domain. The equation is sometimes called the *standard form of the polynomial function.*

***Why can we use an equation to define a function?*** The definition of polynomial function purposefully describes, given a number in the domain, how to determine the value in the range using an expression. It *does not* say, for example (using the squaring function), that . Why? Because is an equation, and equations are about truth values and solutions sets. The equal sign is generally reserved in mathematics for defining equations. However, *most* users of mathematics, for better or for worse, treat statements like *as a formula for defining the function* .

It turns out that using the equal sign to define a function in this way is justifiable but only if students understand that it is a special convention regarding the use of the equal sign. Here is the reasoning behind the convention (using the squaring function named by as an example): For every number in the domain of real numbers, is assigned the value of the expression , and it is also assigned, by definition, the value :

Furthermore, since both of these statements are true for all in the domain, the equation must be true for all . Hence, we do not lose any information by using the convention, “Let , where can be any real number,” to define the function . We are merely stating a formula for and specifying its domain (the formula and domain then specify the range). Of course, the statement is often abbreviated to just, “Let .” Such an abbreviation assumes (and therefore needs to be taught to students explicitly) that the domain of the function is all real numbers and that the range is a subset of all real numbers.

Using the convention above to define and name functions, we often define a function by setting it equal to the expression, and say, for example, “Let , where can be any real number,” or say, “The function has the form for constants with and where can be any real number.” Depending on the context, one either views these statements as defining the function (or form of the function) using a formula or generating an identity statement that is true for all in the domain.

As we alluded to above, we can use any algebraic expression to define a function. In this way, students see that the work that they did in Module 1 on algebraic expressions directly expands the universe of functions available to them in Module 3.

**ALGEBRAIC FUNCTION.** Given an algebraic expression in one variable, an *algebraic function* is a function such that for each real number in the domain , is the value found by substituting the number into all instances of the variable symbol in the algebraic expression and evaluating.

For algebraic functions, it is customary (and often implicitly assumed) to let the domain be the largest subset of the real numbers where the algebraic expression can be evaluated to get numbers. This assumption should also be made explicit to students.

Classwork

Opening Exercise (5 minutes)

This exercise activates prior knowledge about ways to represent a relationship between two sets of numbers. It is intended to set the stage for defining a function using an algebraic expression.

Opening Exercise

Study the representations of a function below. How are these representations alike? How are they different?

These representations are alike because they all match the same pairs of numbers , , , , , and . They are different because they describe the domain, range, and correspondence differently. The table and the function look similar; the input and output are related to domain and range of a function. Evaluating the expression for the given values returns the output values in the table, and the sequence also generates the output values for the first terms starting at .

TABLE:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Input | 0 | 1 | 2 | 3 | 4 | 5 |
| Output | 1 | 2 | 4 | 8 | 16 | 32 |

FUNCTION: DIAGRAM:

0

1

2

3

4

5

1

2

4

8

16

32

Let such that .

SEQUENCE:

Let for where is an integer.

As you review student responses, lead a discussion that highlights the fact that the sequence provides a formula that we can use to quickly generate the terms of the sequence. Ask the class what the explicit formula for this sequence would be. (It would be for , where is an integer.) Remind students that a formula provides an efficient way to describe a sequence of numbers. An explicit formula uses an algebraic expression whose variable is a placeholder for the term number. In a similar fashion, a function can also be defined using algebraic expressions where the variable is a placeholder for an element in the domain. Close this discussion by explaining that perhaps these representations are not so different after all and can all come together under the definition of a function.

Exercise 1 (5 minutes)

This exercise begins to transition students to the idea that we can use an algebraic expression to help us figure out how to match the elements in the domain of a function to the elements in the range.

Exercise 1

Let . Complete the following table using the definition of .

**What are , , , , , and**

**, , , , , and .**

**What is the range of ?**

Briefly discuss student solutions. Point out that the two questions have essentially the same answer. Some students may not have evaluated (listing instead). Point out that technically, evaluating the expression is part of finding the value in the range. One of the goals of this lesson is to define algebraic functions. We will see that evaluating the expression is part of the definition.

**Discussion (7 minutes)**

*Scaffolding:*

Students may notice that the notation looks the same as the way we were writing sequences. The two notations are the same (sequences are functions). Functions provide more flexibility than a sequence because the domain can be any set we choose, not just the positive (or nonnegative) integers.

Discuss with the class the need for a more efficient way to name a function when it is defined by an algebraic expression.

To signify the input/output relationship of and , we write

where the arrow is meant to remind students of the segment they drew in their matching exercises since kindergarten. The arrow also signifies that is matched to (or *mapped* to) one and only one element, .

The precise and compact way to define the function is to state

Let be the function such that .

Display this definition on the board, and have students record it on their student pages. Explain the use of the arrow symbol as well.

* Suppose we let the domain of be the set of integers. What is the range?
  + *The range would be the powers of for integer exponents, .*
* Suppose we let the domain of be the set of all real numbers. What subset of the real numbers would be the range of ?
  + *The range would be all positive real numbers.*
* There are two important parts when we define a function using an algebraic expression. The first part is substituting each element of the domain into the expression and then *evaluating* that expression to obtain the corresponding range element . Typically we would say is , not (although both and are true equations). Make it clear to students that going forward we must *substitute and evaluate* to find each range element.

Exercise 2 (8 minutes)

This exercise works with the squaring function and relates student thinking back to Lesson 9. Have students work with a partner on this exercise. Debrief as a whole class, and make sure to establish the connection that a sequence can be thought of as a function whose domain is the set of or a subset of the non-negative integers. The work in the opening exercise also emphasizes this point.

Exercise 2

The squaring function is defined as follows:

Let be the function such that , where is the set of all real numbers.

**What are , , , , , , , and ?**

**. To understand , remind students that is a placeholder or a blank: , so , and or .**

**What is the range of ?**

**All real numbers greater than or equal to .**

**What subset of the real numbers could be used as the domain of the squaring function to create a range with the same output values as the sequence of square numbers from Lesson 9?**

Let be the set of nonzero integers. Both the set of nonzero integers and the set of positive integers can both be domains for the squaring function. Are there any others? Example: . Have a discussion with your class about why they might want to restrict the domain to just the positive integers. Example: If we wish to think about it as a sequence, we might want to restrict the domain in such a way.

Exercise 3 (8 minutes)

This exercise is designed to prepare students to understand the convention of defining a function by stating, “Let , where can be any real number.” The issue is that the statement uses an “=” sign, so it is defining an equation—not a function—and equations are about truth values and solution sets. However, the exercise below shows that this equation is true for all values of in the domain of , so defining a function by setting it equal to an expression is justifiable. Set this up by directing attention to the opening exercise and asking students to decide whether or not the equation is true for each in the domain of . Talk through the justification for .

Exercise 3

Recall that an equation can either be true or false. Using the function defined by such that , determine whether the equation is true or false for each x in the domain of .

|  |  |  |
| --- | --- | --- |
|  | Is the equation  true or false? | Justification |
|  | True | Substitute 0 into the equation.  The on the left side comes from the definition of , and the value of is also 1, so the equation is true. |
|  | True | Substitute 1 into the equation.  The on the left side comes from the definition of , and the value of on the right is also , so the equation is true. |
|  | True | See above with . |
|  | True | See above with . |
|  | True | See above with . |
|  | True | See above with . |

If the domain of were extended to all real numbers, would the equation still be true for each in the domain of ? Explain your thinking.

Yes. Since maps each , and we agreed to substitute and evaluate the expression to determine the range value for each in the domain, the equation will always be true for every real number .

By the same reasoning as in the exercise, the function

such that

satisfies the equation for all real numbers . Conversely, if some function satisfies an equation, say for example, for all real numbers , then must be defined by the statement

such that .

In other words, we lose absolutely nothing in defining a function by setting it equal to an expression, as in, “Let , where can be any real number.” Not only is this notation more convenient for defining functions with real domains and ranges,[[1]](#footnote-1) the statement can be thought of as a formula and can be thought of as an equation as well.

Exercise 4 (Optional if time allows)

Exercise 4

Write three different polynomial functions such that .

Exercise 5 (3 minutes)

Students evaluate a function and use their work to identify an appropriate domain and range. Based on their work in Grade 8 and in Module 1, students should recall that the radicand should be a non-negative real number. Have them work in pairs or groups on this exercise. Debrief as a whole class, and make sure students record the appropriate domain and range. There are many ways to represent the domain and range intervals as a subset of the real numbers. Some students may describe them in words while others may use an inequality such as to identify the domain.

Exercise 5

The domain and range of this function are not specified. Evaluate the function for several values of . What subset of the real numbers would represent the domain of this function? What subset of the real numbers would represent its range?

Let

, . The square root of a negative number is not a real number. Therefore, the domain of this function must be real numbers greater than or equal to 2. The range is real numbers greater than or equal to 0 since the principal square root of a number is always positive. Using set notation, the domain would be and the range would be .

Closing (4 minutes)

Discuss the lesson summary, and then proceed to the exit ticket to check for understanding. Make sure students understand that the domain of a function is assumed to be all real numbers unless we specify otherwise.

Lesson Summary

ALGEBRAIC FUNCTION. Given an algebraic expression in one variable, an *algebraic function* is a function such that for each real number in the domain , is the value found by substituting the number into all instances of the variable symbol in the algebraic expression and evaluating.

The following notation will be used to define functions going forward. If a domain is not specified it will be assumed to be the set of all real numbers.

For the squaring function, we say Let .

For the exponential function with base 2, we say Let .

When the domain is limited by the expression or the situation to be a subset of the real numbers, it must be specified when the function is defined.

For the square root function, we say Let for .

To define the first 5 triangular numbers, we say Let for where is an integer.  
  
Depending on the context, one either views the statement “ ” as part of defining the function or as an equation that is true for all in the domain of or as a formula.

Exit Ticket (5 minutes)

Students evaluate algebraic functions, identify domain and range, and interpret the meaning of functions in context.

Name \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Date\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

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Exit Ticket

1. Let . Complete the table shown below.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |
|  |  |  |  |  |  |

1. Jenna knits scarves and then sells them on Etsy, an online marketplace. Let represent the cost in dollars to produce from 0 to 6 scarves.
   1. Create a table to show the relationship between the number of scarves and the cost .

* 1. What are the domain and range of ?
  2. What is the meaning of ?
  3. What is the meaning of the solution to the equation ?

Exit Ticket Sample Solutions

1. Let . Complete the table shown below.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |
|  |  |  |  |  |  |

1. Jenna knits scarves and then sells them on Etsy, an online marketplace. Let represent the cost in dollars to produce from to scarves.
   1. Create a table to show the relationship between the number of scarves and the cost .

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| , Number of scarves |  |  |  |  |  |  |
| Cost in  dollars |  |  |  |  |  |  |

* 1. What are the domain and range of ?

and .

* 1. What is the meaning of ?

The cost to produce scarves.

* 1. What is the meaning of the solution to the equation ?

The number of scarves Jenna can knit for a cost of .

Problem Set Sample Solutions

These problems build fluency with identifying the range of a function given its domain and with evaluating functions for various elements in the domain. Students may express the domain and range using the notation shown below or using an alternative method such as an inequality. The following solutions indicate an understanding of the objectives of this lesson:

1. Let and let . Find the value of each function for the given input.
   1. j.
   2. k.
   3. l.
   4. m.
   5. n.
   6. **approx.** o. **approx.**
   7. p.
   8. **12** q. **10**
   9. **24** r. **2,040**
2. Since a variable is a placeholder, we can substitute letters that stand for numbers in for . Let and let , and suppose and are real numbers. Find the value of each function for the given input.
   1. h.
   2. i.
   3. j.
   4. k.
   5. l. **or**
   6. **6** m.
   7. **6h**
3. What is the range of each function given below?
   1. Let .

Range: all real numbers.

* 1. Let .

Range: all positive real numbers.

* 1. Let

Range: .

* 1. Let .

Range: .

* 1. Let such that is a positive integer.

Range: is a positive integer greater than 2.

* 1. Let for .

Range: .

1. Provide a suitable domain and range to complete the definition of each function.
   1. Let

Domain: all real numbers; Range: all real numbers.

* 1. Let .

Domain: all real numbers; Range: all positive real numbers.

* 1. Let , where is the number of calories in a sandwich containing grams of fat.

Domain: all non-negative real numbers; Range: all real numbers greater than or equal to 130.

* 1. Let , where is the number of bacteria at time hours over the course of one day.

Domain: ; Range: .

1. Let , where and are the set of all real numbers and and are real numbers.
   1. Find a function such that the equation is not true for all values of and . Justify your reasoning.

Let . Then, and . The equation is not true because the expression is equivalent to .

* 1. Find a function *f* such that equation is true for all values of and . Justify your reasoning.

Let . Then and . By the distributive property, and that is equal to .

* 1. Let . Find a value for and a value for that makes a true number sentence.

If and , then the equation can be transformed into which is a true number sentence because both expressions are equal to .

1. Given the function whose domain is the set of real numbers, let if is a rational number, and let if is an irrational number.
   1. Explain why is a function.

Each element of the domain (the real numbers) is assigned to one element in the range (the number OR the number ).

* 1. What is the range of ?

Range: .

* 1. Evaluate for each domain value shown below.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |
|  |  |  |  |  |  |

* 1. List three possible solutions to the equation .

Answers will vary: .

1. Students will see the other notation is useful for transformations in 10th, 11th, and 12th grades. [↑](#footnote-ref-1)